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"Capturing Value from Science: A Scientist's Perspective"

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Thank you, and good morning to all. I am honored to be here at this APEC R&D Leaders' Forum among so many distinguished scientists, engineers, and statesmen.

Meetings such as this are an important part of strengthening cooperative international efforts. From the U.S. viewpoint, we value gaining different perspectives and building closer ties with international colleagues.

We all respect and learn from our diverse cultures. As scientists and engineers, we also share a common culture of learning, inquiry, and discovery that reaches across oceans and borders. As we each strive to strengthen our economy's capabilities in research, we also aim to contribute to the cumulative knowledge that lifts the prospects of people everywhere. Our common pursuit of new knowledge is a powerful tool for bringing people together toward the common goal of solving problems and building a world of peace and prosperity. I look forward to learning a great deal from our dialogues today.

I am pleased to speak with you about a topic that is central to the future of each of our economies, and to all of us collectively: *capturing the value of science*.

Let me begin with some general comments to set the stage, and then move on to some specific examples of the approach we've taken to capture value at the U.S. National Science Foundation, the federal agency I help to manage as Director of the Office of Integrative Activities.

There is no doubt that scientific knowledge and technological innovation now play a vital role in our prospects for greater economic and social prosperity. The enormous outpouring of new knowledge over the past several decades has ushered in an era in which science and technology have an impact on our economies far broader and deeper than any previously experienced. In the 21st century, new knowledge and the technological innovation it fosters are driving economic growth, and will determine the quality of life and the health of the planet well into the future.

That makes new knowledge one of the most sought after prizes. Advances in science and engineering have become central to the aspirations of all economies, large and small.

Science and technology have always been a powerful force for human progress. In our own times, more than ever before in history, we have the opportunity to advance global prosperity as we expand the frontiers of knowledge. As we look toward the future, we need a vision that will allow us to sustain this period of unparalleled productivity in discovery and innovation in order to realize the full range of benefits it promises.

Our commitment to international collaboration may well determine how effective we are in realizing this great potential.
In theory, science and engineering have always been international. The results of fundamental research–from the origins of the universe to the fundamental properties of matter, from the interaction of oceans and atmosphere to the human genome – are open to all. In practice, the spread of new knowledge and its applications has often been glacially slow.

Today, that pace is quickening. The revolutionary information and communications technologies of the past twenty years are turning theory into reality.

These technologies—themselves the product of advances in science and engineering—have literally swept across the globe. We can collect, store, and manipulate vast quantities of data.   We can share those data and communicate new knowledge instantaneously. These capabilities open new doors for international collaboration that were unworkable only ten or fifteen years ago.

These tools are also changing the very way we conduct research and creating a new science of the 21st century. When we dramatically advance the speed of scientific research in any area, we give ourselves the mechanism to reach a frontier much faster. Or, better yet, to reach a new frontier that had been unreachable, as well as unknowable.

In many areas of research, scientific progress requires the cross-fertilization of ideas, models, and experimental platforms from many disciplines. Modern biotechnology has developed with contributions from a broad range of disciplines: biology, chemistry, physics, mathematics, engineering, and computer science. Nanoscale science and engineering – one of the potentially revolutionary technologies of the 21st century – calls upon an equally diverse range of disciplines.

Science is becoming a science of *communication and collaboration – especially* international collaboration. We need ideas not only from a broad range of specialties, but also from different geographic regions and from all cultures. The increasing complexity and pace of discovery, the need for multidisciplinary approaches, and the global nature of much research, require that we draw on different perspectives to solve common problems. We must find new ways for scientists and engineers around the world to work together.

You may be thinking that this is applicable only when we are addressing international cooperation in fundamental research.   How can we reconcile this collaborative, collegial international environment with the hard realities of the competitive global marketplace?

To provide some suggestions about possible approaches to these complex issues, I turn now to some approaches suggested by our experience at the National Science Foundation.

First, a few words about the Foundation. NSF supports fundamental research in science, mathematics, and engineering across all fields, and promotes excellence in science, engineering and mathematics education at all levels. We are committed to preparing a world-class science and engineering workforce that is globally engaged and prepared for the challenges of a rapidly changing science and technology enterprise. That is as much a part of our mission as discovery.

Our vision for the future of NSF is to remain steadfastly focused on the frontiers of knowledge, and our vision statement reflects that. It is crisp and direct: "Enabling the nation's future through discovery, learning, and innovation." The key to this vision is giving "learning" and "innovation" equal billing with "discovery."

It has always been clear that research and education go hand in hand. Bringing them into dynamic relationship with innovation is a more recent development.

Advances in science and engineering knowledge are linked more intimately with innovation than ever before. We now realize that scientific research and technological innovation drive each other. In the larger sense, innovation depends upon a mutual, synergistic set of interactions that includes not only science, engineering and technology, but social, political and economic interactions as well. The pace of both scientific progress and technological innovation has increased together.

Over the fifty years of NSF's existence, we have learned some lessons about how to realize the full value of the triumvirate "discovery, learning, and innovation." Two overarching approaches stand apart from all the rest: the development of collaborative partnerships and the integration of research and education. Both are vital to capturing the *full* value of science and engineering research.

An example of how this works in practice is the NSF Science and Technology Centers: Integrative Partnerships Program. I have chosen this program for two reasons. First, it has become a catalyst for the design and planning of other NSF programs. And secondly, it is near and dear to my heart because it is one of the programs that I am directly responsible for implementing at the Foundation. Call it a father's pride in a growing child!

The Science and Technology Centers Program facilitates fundamental research by assembling the critical mass of people, ideas and tools required to address important research problems that are complex, interdisciplinary, costly, risky or—frequently—exhibit a combination of these features. But it also encourages technology transfer through integrative partnerships among academe, industry, government, and other institutions. By integrating the education of undergraduate and graduate students into these research activities, the centers enhance their training and provide them with an awareness of potential applications for scientific discoveries. They can move with agility among academe, industry and government, transferring ideas and expertise.

An example of how this works is the NSF-supported Center for Adaptive Optics. This portrays how advances in one field have resonated in another. A new tool invented for a precise purpose may actually find service in many disciplines. Here in adaptive optics--a striking consilience of astronomy with vision science--the biological and physical sciences cross-fertilize in unexpected ways.

Adaptive optics sharpens astronomers' vision from ground–based observatories, an improvement once referred to as "taking the twinkle out of stars." It is a technique developed for astronomy that compensates for wave front distortion induced by atmospheric turbulence.

When used to look at the human eye, adaptive optics produced the first images of cone arrangements in the living eye. This marriage between astronomy and vision science has now led to the development of a MEMES-based Adaptive Optics device that automatically obtains the optimal vision correction during eye exams. A future version of the device will incorporate retinal imaging, improving the ability of clinicians to diagnose and treat retinal diseases that cause blindness.

The device is a result of a unique collaboration between universities, national laboratories, optical component manufacturers, and one of the world's leading providers of custom contact lenses and refractive eye surgery equipment.

The Center researchers—and those of us who worked with them to initiate the Center—did not foresee these developments, but they now encourage further exchanges by bringing together young students from astronomy and vision science. They visit each other's laboratories and are enriching each other's perspectives at a formative time in their careers.

The Center reaches even further in an effort to develop the talents of our youngest citizens. Each summer, the Center conducts a four-week course, named The Stars, Sight and Science, designed and taught by Center scientists to teach secondary school students about adaptive optics and how it is used in astronomy and vision science. Along the way, youngsters engage in real research, and learn about physics, astronomy, engineering and vision science through the lens of adaptive optics. This program also provides professional development opportunities for graduate students and post docs learn how to teach hands-on, inquiry-based science. Since this center also involves 5 major universities distributed to the far reaches of the United States, improved information technology and improved communication networks have facilitated the transfer of knowledge and multi-directional learning. This is truly a virtual center or a center without walls.

I want to elaborate on the Centers concept because it has become a template for many programs at NSF. Those of us who work with this program recognized early on that the centers could become a template for integration and collaboration in NSF program-design. The success of this recipe led NSF to replicate integration and collaboration in its many forms in diverse centers. These centers have helped the U.S. remain nimble and on the cutting edge in today's fast-paced knowledge economy. Consider for a moment the partial list of categories for major NSF centers—science and technology centers, engineering research centers, supercomputing centers, mathematics centers, partnerships for innovation, and most recently, science of learning centers.

The components of the formula are simple and allow for maximum flexibility. Many of you know these ingredients and outcomes from the development of centers in your own economies. NSF provides seed money, which is leveraged, more than 10 times through industry and other sources of center support. When NSF support is used in this way it automatically brings in new ideas and expertise. Thus the seed money provides a meeting ground where many interested parties can gather.

There was a time, in the 60s and early 70s, when the norm was 20 years for the results of fundamental research to find their way to the marketplace. Today, in many instances, that timeframe has collapsed, often to 20 months or even less. The pace of technological change has accelerated dramatically with the advent of more powerful and sophisticated tools both enabling more creative disruption at the frontier of knowledge and reducing time lag between discovery and application.

However, another major underlying cause for this change has been the links made between and among the principal players. The barriers between sectors have diminished, due in large part to changes in the sociology of science and engineering brought about by *integration and collaboration*. With university researchers working with those in industry on a common problem, the time from lab to marketplace shortens.

In addition, a new collegiality grows and very different sectors come to appreciate each other's culture and goals, and find a way to braid them into a pattern of mutual success.

Among the fundamental values that NSF brings to the centers structure is the responsibility for each party to participate as both a teacher and a learner. This is not a one-way street where one party gives and the other receives. There is both opportunity and responsibility to teach as well as learn.

In addition, NSF understands the value of having all team members participate from the onset of a project when each can have a voice at the front end in deciding the parameters and responsibilities of the work to be done.

Another important value instilled in the process is the understanding that teams and centers should eventually be able to stand on their own, independent of NSF support. This has happened in frequently.

In the big picture, however, the long-term value of centers as a training-ground for graduate and undergraduate students—in an environment that partners academe, industry and government—is paramount. As university, government, and industry researchers work side-by-side, these arrangements provide unique opportunities for training the fresh talent needed in the workforce.

This is a pattern that we could well emulate in structuring our international collaborations.

Many research challenges are inherently global and will require an international effort to resolve. We all have a stake in advancing understanding of emerging infectious diseases, the dynamics that shape our planet and cause earthquakes and volcanic eruptions, the complex interactions among air, land and sea that shape global climate, to name just a few. International collaboration will speed us along as we begin unraveling the staggering complexity that pervades these phenomena.

We need to reach beyond current models of cooperation and make the most of the powerful new tools at hand. One path might be the virtual collaboratory, an example of which is the U.S. Network for Earthquake Engineering Simulation. NEES – as we call it – is a 21st century model of collaboration – literally, a laboratory without walls or clocks.

Researchers at approximately 20 geographically distributed equipment sites are linked through high-speed Internet connections. They can access earthquake engineering data and high performance computational tools, operate equipment, construct physical or numerical simulations and visualizations, and observe experiments from anywhere on the net.

Over time, NEES will grow, as other sites with unique experimental capabilities join the network. NSF envisions NEES as a virtual *international* collaboratory with experimental and analytical resources distributed around the globe.

Cyberinfrastructure—the nexus of information, communication, and collaboration tools that empower today's research, education, and innovation enterprise—is now indispensable to economies worldwide. NSF's objective is to identify and link communities of researchers across international boundaries to facilitate communication and collaboration between the United States and the international scientific community. It is also an opportunity to reach out to those not normally served by existing regional networks.

Just this past December, the NSF, a broad consortium of Russian ministries and science organizations and the Chinese Academy of Sciences announced the start of operations of “Little GLORIAD”—the first round-the-world computer network ring. As the name suggests, Little GLORIAD is a first step towards a higher-speed network—GLORIAD, shorthand for Global Ring Network for Advanced Application Development—that the three countries are jointly developing for a mid-2004 start. GLORIAD is proposed to be a 10-gigabit-per-second optical network around the entire northern hemisphere.

The new network will facilitate joint scientific and educational projects, and vastly improve the reliability and flexibility of researchers as they address common scientific issues, for example, responses to natural disasters, better understanding of the human genome, and distributed monitoring of seismic events, to name only a few.

The network will also enable collaborations between universities and local schools, such as shared seminars, distance-learning programs and multi-national science fairs.

We need to recognize that outreach to young people and to classrooms is an essential feature of a collaborative and integrative approach. Today, and for the far future, the well being of individuals and the robustness of every economy will depend on knowledge and skills in science, engineering, and technology. How well we prepare *each* of our citizens in these areas will determine how well each of our nations is prepared to contribute to global prosperity and participate in its benefits.

The challenge is a monumental one: how do we best nurture and develop the abundant talent of our young people? How do we prepare them for an increasingly complex and interdependent world where skills in math and science are necessary to flourish? And how do we ensure that a significant number of them will choose careers in science and engineering?

Knowledge about learning and experience with educational innovation is only just beginning to emerge. I believe we could all benefit greatly from dialogue on these issues.

Nothing we can do in the international community of science could be more important than providing world class science and mathematics education for our youngsters, and opportunities for our young scientists and engineers to participate in international activities. The transparency and openness of science and engineering are capabilities and responsibilities that we can foster among our students by providing them with opportunities—at all levels of study—to work in international research teams. They also need these opportunities to share perspectives and build friendships to ensure even greater international cooperation in the future.

As we develop these new ways to work together, we will speed the application of new knowledge to common problems. We can learn how to adapt successful models to our own regional circumstances. And we can extend international cooperation to countries large or small that are still struggling to develop a strong science and engineering base.

Let me conclude with this final thought. We are fortunate to be scientists, engineers, and educators at the beginning of the 21st century. Whole new territories of knowledge are on the horizon, with the promise of major advances just ahead. We can begin to envision how new knowledge and technological innovation can help us solve some of the seemingly intractable problems that confront us regionally and around the globe.

Thank you.